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APPLYING COMMERCIAL PROCEDURES AND TECHNOLOGY TO THE UNITED STATES NAVY'S MATERIAL INVENTORY VALIDITY

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APPLYING COMMERCIAL PROCEDURES AND TECHNOLOGY TO THE UNITED STATES NAVY'S MATERIAL INVENTORY VALIDITY

June 2021

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The Department of the Navy (DON) is faced with the need to improve inventory accuracy in order to increase readiness in multiple theaters. There are many commercial logistics organizations that excel at warehousing, supply chain management, and transportation; the DON has the opportunity to evaluate whether to adopt innovative technologies to improve its material accountability and readiness. This study examines the logistics model of high-profile, successful organizations to identify processes and technologies that would be potential adoption candidates to enable real-time audit for the DON. Further, the study conducts a cost-benefit analysis to determine the best-value technological tools for acquisition by the DON. The findings suggest that purchasing Automated Mobile Robot technology by Fetch Robotics is the most beneficial alternative for real-time inventory accountability.

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APPLYING COMMERCIAL PROCEDURES AND TECHNOLOGY TO THE UNITED STATES NAVY'S MATERIAL INVENTORY VALIDITY

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ABSTRACT

The Department of the Navy (DON) is faced with the need to improve inventory accuracy in order to increase readiness in multiple theaters. There are many commercial logistics organizations that excel at warehousing, supply chain management, and transportation; the DON has the opportunity to evaluate whether to adopt innovative technologies to improve its material accountability and readiness. This study examines the logistics model of high-profile, successful organizations to identify processes and technologies that would be potential adoption candidates to enable real-time audit for the DON. Further, the study conducts a cost-benefit analysis to determine the best-value technological tools for acquisition by the DON. The findings suggest that purchasing Automated Mobile Robot technology by Fetch Robotics is the most beneficial alternative for real-time inventory accountability.

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LIST OF ACRONYMS AND ABBREVIATIONS

AMR	autonomous mobile robot
ATAC	Advanced Traceability and Control
CG	guided missile cruiser
CO	commanding officer
COMNAVSURFOR	Commander, Naval Surface Forces
COMNAVSURFPAC	Commander, Naval Surface Forces, United States Pacific Fleet
COMPACFLT	Commander, United States Pacific Fleet
DBI	demand-based item
DDG	guided missile destroyer
DLR	depot-level repairable
DOD	Department of Defense
DON	Department of the Navy
FACET	Fleet Audit Compliance Enhancement Tool
FIAR	Financial Improvement and Audit Readiness
FIMARS	Force Inventory Management Analysis Reporting System
FLC	Fleet Logistics Center
GAO	Government Accountability Office
IBS	Integrated Barcode System
IOC	Inventory Operations Center
LAP	location audit processing
LCS	littoral combat ship
LHA	amphibious light aircraft carrier
LHD	amphibious helicopter carrier
LPD	amphibious transport docking ship
LSD	amphibious dock landing ship
MEPP	Material Exploratory Pilot Program
MSU	mobile storage unit
NAVAIR	Naval Air Systems Command
NAVSUP	Commander, Naval Supply Systems Command
OPTAR	end-use operational target

RFID	radio frequency identification
SIM	selected item management
SUPPO	supply officer
USMC	United States Marine Corps
USN	United States Navy
WSS	Weapons Systems Support

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I. INTRODUCTION

To prepare for periodic Department of Defense (DOD) audits, the Department of the Navy (DON) implemented Financial Improvement and Audit Readiness (FIAR) endeavors to find and address discrepancies in the DON's in-house activities that influence the accuracy of inventory and financial statements. These initiatives augmented existing inventory and procedural requirements and milestones in Commander, Naval Surface Forces, U.S. Pacific Fleet's (2016) *Surface Force Supply Procedures* (COMNAVSURFPACINST/COMNAVSURFLANTINST 4400.1A). Due to the DON's constant deployments worldwide, the DON faces unique challenges when it comes to creating and maintaining standard procedures along with a record of purchases, receipts, and on-hand inventories of spare materials, subsistence items, and wholesale repairable equipment on both afloat and remotely located ashore units. Most U.S. Navy (USN) ships and shore-based fleet logistics centers (FLCs) employed new processes to easily recall audit-related documents from a central repository over the last 4 years; however, significant issues were identified in the efficacy of these processes that, if not addressed, would lead to significantly increased risks of inventory inaccuracy in the shore-based facilities that support deployed units and both material and procedural audit failures in afloat units (Lavery & Spracklin, 2016). For example, Reuters associate Mike Stone reported that, in 2019, the Pentagon rated an FLC site's audit as unsatisfactory when it "identified $81 million worth of active material not tracked in the inventory system" with an additional 4.6 acres of "unneeded equipment" that were identified and eliminated (Stone, 2019). In light of recent DOD testimony before a U.S. Senate panel "that it will take years to eventually pass a full [inventory and accounting] audit," there is an urgent need to evaluate the shortcomings of the new inventory processes and identify ways to improve effectiveness (Stone, 2019). Therefore, there is a clear need that the DON works to improve its inventory processes. The aim of this study is to identify commercial logistics organizations that excel at inventory and carefully examine their processes and technology and their suitability for by the DON to enable real-time audit.

A. RESEARCH QUESTION AND METHODOLOGY

This research study attempts to address the following research question:

What processes and technologies can the DON adopt from private industry best-practices to increase their inventory accuracy and improve their responsiveness to supply-related requirements?

Through answering this question, the research will use the following stepwise methodology:

1. Examine the existing material readiness audit processes and the standard metrics in place for the DON.
2. Identify the root causes of DON asset performance.
3. Identify and assess alternative processes, technologies, managerial styles, and organizational cultures from commercial entities.
4. Compare DON standard metrics and performance with those from commercial entities regarding the ability to increase their inventory accuracy and improve their responsiveness to supply-related requirements.
5. Formulate recommendations for processes, technologies, managerial styles, and organizational cultures the DON can adopt.

In order to address the research question, this study uses a review of both scholarly writings as well as empirical data and cases. Reviewing literature that includes past analyses of DON operating procedures and historical metrics helps to identify further opportunities and challenges unique to DON organizations. Then, this study examines the technologies adopted by Zappos, XPO Logistics, and FLC Jacksonville to compare the potential fit and tradeoffs of implementing similar changes in today's Navy.

Opportunities to adopt new technologies and processes exist at each level of the Navy Supply system and within the variety of supporting establishments. An analysis of data measures on the real-time inventory accuracy of Zappos, XPO Logistics, and FLC Jacksonville using a cost-benefit approach allows to summarize the opportunities and tradeoffs from adopting similar technologies by the DON from its commercial counterparts. Further, this study addresses the feasibility of adopting and maintaining innovative technologies, business practices, and managerial methods within organizations that would most directly support afloat operational commands with accurate inventories and streamlined, timely processes.

B. BENEFITS AND LIMITATIONS

This research study aims to provide recommendations on technologies that can improve the overall inventory accuracy of the U.S. naval fleet.

The general focus is on examining and applying procedures and new technologies used by selected commercial organizations to the current processes used by DON to record and track key supporting documentation for inventory audits. The goal is to significantly curtail the risk of inventory discrepancies and inspection failures due to poor supporting documentation or due to delayed responses to documentation requests from an auditor. The recommendations in this study aim to increase the efficiency of current processes in the DON, conserve man-hours used for document retention, verification, and rework, and improve the quality of work from personnel directly associated with the DON's processes.

Because of time and scope limitations, the focus of this study is narrowed to three established and reputable logistics organizations for the analysis of their material processes and technologies feasible for adoption by the DON: Zappos, XPO Logistics, and Commander, Naval Supply Systems Command (NAVSUP) Fleet Logistics Center (FLC) Jacksonville. The study's analysis and conclusions are based on the amount of data collected from these organizations and the NAVSUP Weapons Systems Support (WSS) Inventory Operations Center (IOC). Therefore, follow-up research may be needed to substantiate and generalize findings.

C. ORGANIZATION OF STUDY

This research is organized in five chapters, including this introduction chapter. Chapter II provides background information on why the DON holds inventory accuracy as a high priority and it presents a review of prior studies that explore the opportunities and tradeoffs on technologies and processes the DON considered and adopted from commercial entities. Chapter III provides empirical data and cases within Zappos, XPO Logistics, and FLC Jacksonville that interrelate processes and technologies to performance metrics, while Chapter IV presents the steps for a cost-benefit analysis to determine the feasibility of adoption by the DON. Chapter V contains a synthesis of the facts and data identified in the previous chapters and presents a solution with recommendations on how to begin moving toward the solution; it also provides areas for future research.

II. BACKGROUND AND LITERATURE REVIEW

This chapter presents the key elements of the DON's inventory policies, adopted commercial technologies, and their management practices used to improve inventory accuracy. This chapter also reviews studies that use cost-benefit analyses to determine the overall feasibility of choices presented to organizations. Combining these topics provides an understanding of why the DON holds material inventory accuracy as a high priority, and it should determine whether correlations exist between innovation adoption, cost savings, quality of life improvements for workers, and improved organizational performance.

A. THE NAVY'S METRICS FOR HIGH-VELOCITY, HIGH MONEY VALUE ASSETS

This section covers metrics and policies established by overarching DON authorities that are responsible for the materials held in warehouses and storerooms on both afloat and ashore U.S. Navy assets.

1. NAVSUP

NAVSUP generally regards inventory accuracy percentages as "vital to cost effective support" and a principal metric for effective material management (Commander, Naval Supply Systems Command [NAVSUP] Weapons Systems Support [WSS], 2017). Inventory accuracy impacts are thoroughly delineated in chapter 6 of the *Operational Forces Supply Procedures* manual:

> The impact of inventory accuracy ranges from audit readiness to Department of Defense (DOD) budget credibility. There is a negative impact on readiness when material on an accountable record cannot be found. If the accountable record is overstated, nonexistent assets are applied to requirements. The opportunity for undetected theft is increased when accountable records do not agree with material in storage. (Commander, Naval Supply Systems Command [NAVSUP], Chapter 6, para. 6000)

NAVSUP requires a wall-to-wall, physical count of all materials within a storeroom onboard a ship or a warehouse in a shore-based establishment if they contain high money value assets such as depot-level repairable items (DLRs). Additionally, NAVSUP requires demand-based item (DBI) and selected item management (SIM) velocity inventories, which are "a periodic physical count of all stock items that experience relatively frequent demands (fast movers)" (NAVSUP, 2020). Table 1 shows NAVSUP's requirements for inventory accuracy rates, with Category A applying to all high money value assets and Category B applying to all other material, including high-velocity assets.

Table 1. Mandated Inventory Accuracy Rates. Source: NAVSUP (2020).

Category	Sub-Population	Goal	Tolerance
A	Unit price > $1,000 and all DLRs	99%	99%
B	All other material	95%	95%
C	Controlled inventory items (see paragraph 6062)	100%	100%
95 PERCENT CONFIDENCE LEVEL +4 PERCENT BOUND APPLICABLE TO EACH CATEGORY			

To ensure that both ship and shore-based custodians meet inventory accuracy requirements, NAVSUP details specific procedures for preparing, executing, and reconciling inventories. Prior to a physical inventory, all items must be consolidated, organized, and clearly identified with their labels displayed in plain sight (NAVSUP, 2020). During the inventory, the "Count/Recount" method is required, where one party matches on-hand quantities to the inventory on record and a second party verifies all inventory discrepancies identified by the first (NAVSUP, 2020). If inventory discrepancies persist, a third count is performed and verified by the supervisor of the inventory (Commander, Naval Supply Systems Command [NAVSUP], 2021).

NAVSUP's procedures theoretically culminate in total asset visibility throughout the USN's ashore and afloat stock control points. This visibility is critical to the USN's operational efficiency and its supply system's responsiveness to dynamic conditions in certain operational theaters by "[ensuring] that high priority requirements can be sourced under limited stockage conditions" (NAVSUP, 2020). To facilitate visibility, NAVSUP requires all afloat vessels to upload their on-hand inventories to the Force Inventory Management Analysis Reporting System (FIMARS) on the 10th and 25th of each month (NAVSUP, 2020).

NAVSUP regards its frequent inspections to verify procedural compliance and satisfactory inventory accuracy as "a team effort to constructively improve the NAVSUP Enterprise's performance in providing warfighters with global logistics services that support and sustain combat capabilities and operational readiness" (Commander, Naval Supply Systems Command [NAVSUP], 2018). In light of this, inspectors frequently publish best practices that they discover when visiting stock control points and assessing their inventory accuracy.

2. Commander, Naval Surface Forces, U.S. Pacific Fleet

Commander, Naval Surface Forces, U.S. Pacific Fleet (COMNAVSURFPAC) is the overarching authority for the Naval surface forces homeported and operating in the areas of the U.S. West Coast, Alaska, Hawaii, and the Western Pacific Ocean. The surface forces governed by COMNAVSURFPAC include guided missile destroyers (DDGs), guided missile cruisers (CGs), amphibious dock landing ships (LSDs), littoral combat ships (LCSs), amphibious transport docking ships (LPDs), amphibious helicopter carriers (LHDs), and America-class amphibious light aircraft carriers (LHAs).

COMNAVSURFPAC regards inventory accuracy as a benchmark for a ship's overall operational readiness. Inventory accuracy requirements not only count the correct number of selected items; they also ensure items are in the correct locations via location audit processing procedures (LAPs). LAPs and inventories must be conducted on a regular basis, but they must be scrutinized more closely when a supply officer (SUPPO) is being relieved of their duties (Commander, Naval Surface Forces, U.S. Pacific Fleet [COMNAVSURFPAC], 2016). Figure 1 shows COMNAVSURFPAC's requirements for sampling inventories of SIMs, DBIs, LAPs, and DLRs.

4. The relieving officer conducted a sample inventory and location audit of a random selection of items as per reference (b) to determine the validity of stock records.

a. SIM/DBI: 10% sample inventory conducted (XXX of XXX line items). Inventory validity is 99%.

b. Non-SIM: 0.25% sample inventory conducted (XXX of XXX line items). Inventory validity is 99%.

c. LAP: 0.25% sample inventory of total line items conducted. Inventory validity is 99%.

d. DLR: 100% sample inventory conducted (XXX of XXX line items). Inventory validity is 100%.

e. Food Service: 100% inventory conducted (XXX of XXX total line items). Inventory validity is 99%.

f. Retail: 50 line item inventory conducted with 100% validity. 25 line item price check with 100% accuracy.

Figure 1. Inventory Section of the Joint SUPPO Relieving Letter. Source: COMNAVSURFPAC (2016).

Additionally, it is COMNAVSURFPAC policy for a ship's Supply Department to maintain constant accountability of DLRs onboard and to keep the ship's commanding officer (CO) informed of DLR inventory through daily 8 O'Clock Reports and a comprehensive monthly report that outlines supply operations (COMNAVSURFPAC, 2016). The milestone for DLR inventory validity is 100%; missing DLRs must be "aggressively researched, surveyed and processed within 10 working days of discovery" (COMNAVSURFPAC, 2016). Additionally, items categorized as SIM or DBI must also have 100% inventory validity (COMNAVSURFPAC, 2016).

The Supply Department's monthly report to the CO must also include the current fiscal year's inventory schedules, the dates that inventories are actually completed, the number of items that were inventoried, and the percent accuracy of the inventory conducted. Figure 2 shows an example of how to compose this section of the report.

PART II - INVENTORY MANAGEMENT

1. FY12 Inventory Schedule

INVENTORY TYPE	SCHEDULED	DATE COMPLETED	# ITEMS	ACC. RATE (%)	NOTES
SIM/DBI/POS	14NOV11-20NOV11	20NOV11	350	98%	
BMS	10DEC11-15DEC11	20DEC11	5	100%	1
CLASSIFIED	10JAN12-15JAN12	15JAN12	1	100%	
HAZMAT	14FEB12-19FEB12	25FEB12	195	76%	2
DLR (B STRM)	10OCT11-14OCT11	12OCT11	824	99%	3
DLR (E STRM)	3SEP12-10SEP12				
SIM/DBI/POS	6AUG12-13AUG12				
BMS	10SEP12-15SEP12				

Note 1: Inventory conducted earlier due to custodian transferring.
Note 2: Low accuracy rate caused by incorrect issuing procedures. Training conducted.
Note 3: Surveys completed.

2. Monthly Spot Inventories (As Required)

INVENTORY TYPE	# ITEMS	ACC. RATE (%)	REMARKS
SIM/DBI/POS	111	99%	
DLR (B STRM)	50	100%	
NON-SIM/NON-POS	250	96%	$4,825.00 LBIs generated, no survey
MAMS (CF01)	802	100%	Relief of CSO
MAMS (EA01)	36	100%	Relief of EN2 Gear

Figure 2. An Illustration of the Inventory Section of the Supply Officer's Monthly Report to the CO. Source: COMNAVSURFPAC (2016).

To align with NAVSUP's inventory accuracy metrics and its vision of total asset visibility, COMNAVSURFPAC's inspectors require its afloat activities to "provide accurate, timely, and complete documents to verify ordered items were received" (COMNAVSURFPAC, 2016).

B. TECHNOLOGIES AND PROCESSES ADOPTED BY THE NAVY

This section covers innovations and procedures that the DON adopted and implemented in overarching policies in an attempt to improve its auditability readiness and inventory accuracy.

1. Fleet Audit Compliance and Enhancement Tool

COMNAVSURFPAC acquired the Fleet Audit Compliance and Enhancement Tool (FACET) to support the Commander, U.S. Pacific Fleet's (COMPACFLT's) objectives for properly, accurately, and completely maintaining records of receipt documentation for all materials needing inventory. FACET provides surface forces with the ability to scan receipt documentation into a paperless, cloud-based database for indexing in the event of an inventory audit. According to a COMNAVSURFPAC message to its surface forces, if surface forces have FACET installed onboard, they "are required to scan all documents related to [material] transactions from initial order to final receipt and acceptance of the material" (Lavery & Spracklin, 2016). The thorough documentation of this process applies especially to the materials that are ordered often and/or have a high monetary value, in order to prevent erroneous reordering or reports of lost shipments, both of which adversely affect surface force operational target (OPTAR) funds.

2. Integrated Barcode System

The Integrated Barcode System (IBS) is the USN's semi-automated inventory technology that is in place on both its afloat vessels and its shore-based warehouses. The system is comprised of barcode scanners, barcode printers, and docks that connect to the USN's Navy Marine Corps Intranet (NMCI) to transfer information to and from Relational Supply (RSUPPLY) on afloat units and Enterprise Resource Planning (ERP) in shore-based facilities.

The system functions using the following process: an inventory record containing a national stock number (NSN) is manually added to RSUPPLY or ERP. Once the record is built into RSUPPLY or ERP, the information is synced to IBS in order to receive new materials with the same NSN or take inventory of items with the same NSN. The scanner stores the number of barcodes containing the same NSNs in its internal memory until the scanner is returned to the dock, where it either adds newly received materials to corresponding locations, or it compares inventoried materials to the amount on-hand in either RSUPPLY or ERP. RSUPPLY or ERP will then generate a report of inventory discrepancies by NSN or by inventory location, and a second or third count will be required to verify the inventory.

When taking inventory of materials in a location, a location barcode must be scanned first. Additionally, in order to stow new materials, a location barcode must be scanned before scanning the barcode of the individual item.

3. Advanced Traceability and Control Processes

The USN first implemented Advanced Traceability and Control (ATAC) processes in 1986 to improve inventory accuracy and transparency for DLRs in transit from stock control points to designated overhaul points. ATAC processes involve the use of "commercial freight agent [functions] to increase the traceability and movement of [retrograde DLRs]" (Pritchard, 1992). According to NAVSUP WSS Philadelphia's Repairables Distribution Division Director, Nancy Powers (email to author, February 25, 2021), since its adoption, the ATAC process evolved from having only two ATAC hubs located in Norfolk, VA and San Diego, CA to including more than 22 nodes located in USN and U.S. Marine Corps (USMC) bases throughout the world. This was in an effort to maintain inventory accuracy of transient DLRs as USN and USMC operations increased in geographical scope. Figure 3 shows the locations of each ATAC hub and node throughout the world.

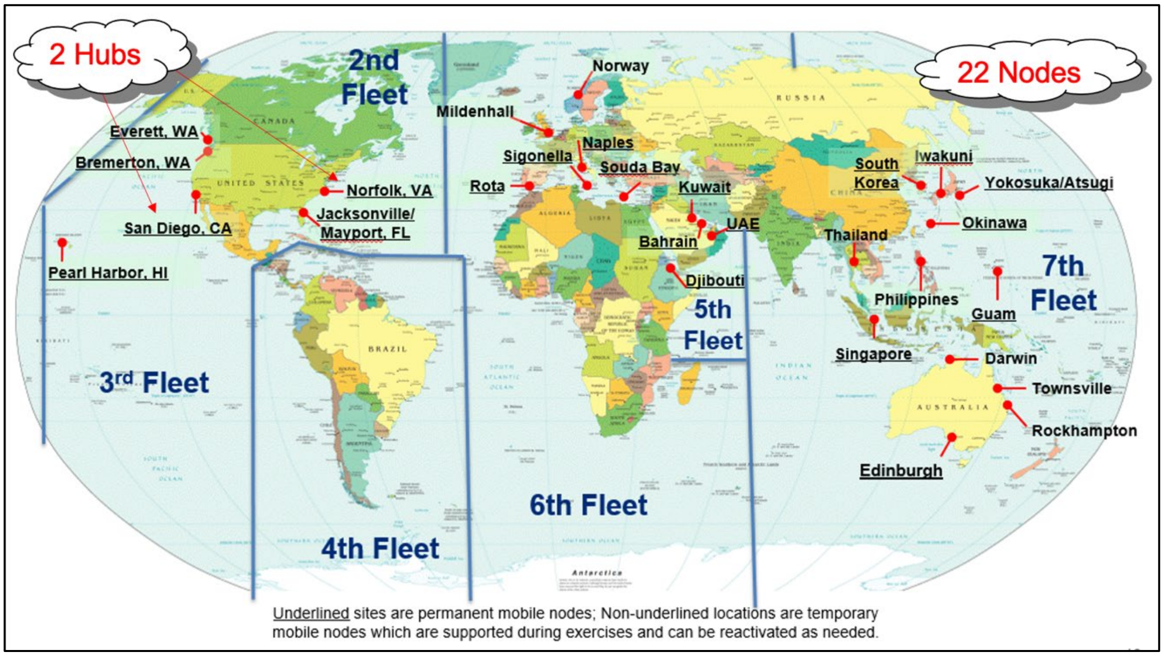


Figure 3. Location of Temporary and Permanent ATAC Hubs and Nodes. Source: B. Day (email to Nancy Powers, provided to the author, February 25, 2021).

ATAC's processes ensure that DLRs pass through a specific procedure to maintain inventory visibility. First, DLRs and other high value assets are received at a hub or node. For each item that ATAC receives, receiving personnel input information into the Electronic Retrograde Management System (eRMS) either through a barcode scan or manually. Next, screening personnel input each item's information, including its serial number, into another section of eRMS, and a supervisor verifies the accuracy of each input. Once verified, eRMS automatically generates paperwork for disposition and shipping. Packaging personnel then determine packaging requirements for each item to be shipped safely, and they pack the items accordingly for shipment. Lastly, shipping personnel create a manifest in eRMS and send each item to its designated overhaul point. Proofs of shipment and delivery are recorded by shipping personnel when they are available (N. Powers, email to author, February 25, 2021).

C. TECHNOLOGIES CONSIDERED BY THE NAVY

This section covers innovations and procedures that the DON conducted studies and demonstrations on to improve its auditability readiness and inventory accuracy. However, the DON did not adopt these technologies and innovations due to limitations on how they could be implemented on U.S. Navy assets.

1. Radio Frequency Identification

According to the *DOD Suppliers' Passive RFID Information Guide*, Radio Frequency Identification (RFID) is a transformational technology intended to optimize supply chain management, and its benefits include improved inventory accuracy, elimination of duplicate requisitions that meet the same individual requirement, improved real-time visibility of assets in transit, and an automated receipt process (Department of Defense [DOD], 2021). RFID differs from the technologies used with IBS because its processes and information require less human interaction with an item, and it does not require direct line of sight to obtain information (Brown, 2007). According to an analysis performed by Naval Postgraduate School professors Geraldo Ferrer, Nicholas Dew, and Uday Apte, RFID "is a sophisticated information technology that can be readily used to support and enhance service operations" if its application reduces labor intensity and errors due to the volume of work and increases "the perceived customization of professional services" (Ferrer, Dew, & Apte, 2010).

There are two types of RFID technology available to the DOD: active and passive. Active tags have their own power source and can send information through their own transmitters, while passive tags utilize the signals transmitted by RFID readers for power. Passive tags are therefore lighter in weight, less expensive, and not dependent on battery life; however, they have "shorter read ranges, more limited data storage than active tags and require a higher-powered reader" (DON CIO Spectrum Team, 2004). Figure 4 shows the components of a passive RFID system.

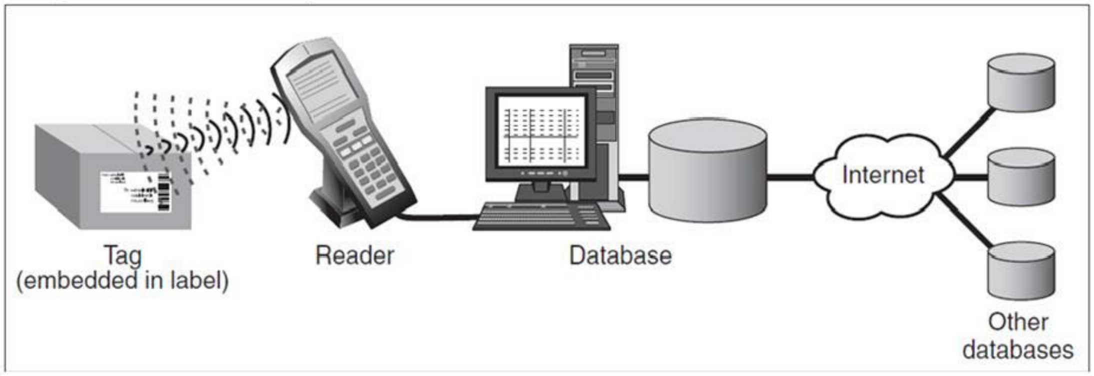


Figure 4. Passive RFID System Components. Source: Burke and Ewing (2014).

Because passive RFID tags are dependent on readers to power themselves and transmit information, they can be integrated into shipping labels for logistical purposes. Regardless of whether they are already within a shipping label or provided separately, the DOD requires all RFID labels to be affixed in "a suitable location where there is a minimum risk of damage and highest potential for successful [scanning by a reader]" that has a clearance of 5 centimeters, or 2 inches, away from any edge (DOD, 2021). Additionally, all RFID labels cannot be placed over a package's seam or in any area that will be covered by sealing tape, nor can they overlap with or be within 10 centimeters, or 4 inches, from any other RFID label on the package (DOD, 2021).

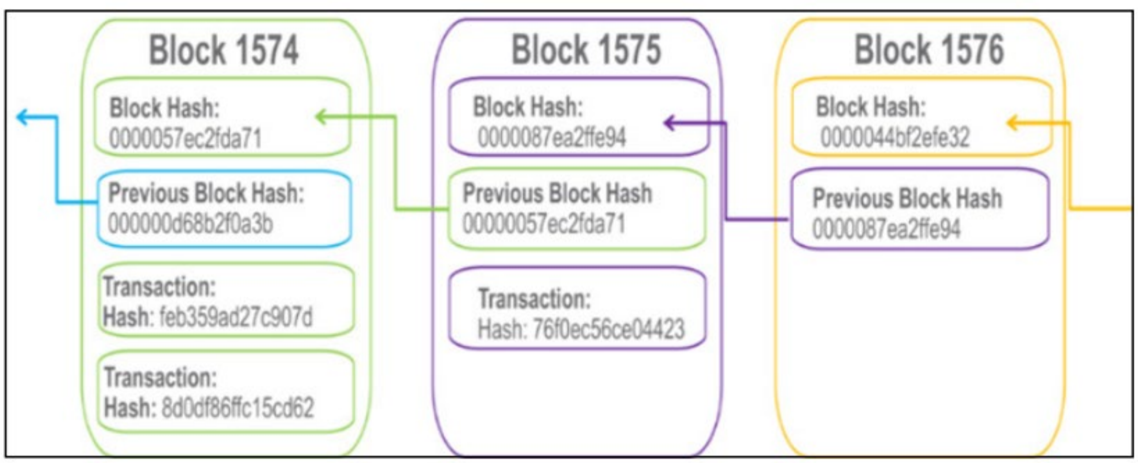
Although the DOD "has been a primary driver of RFID implementations through its mandates," there is limited capacity for the USN to adopt this technology (Doerr et al., 2006). With IBS established as a common and mature system on afloat vessels, the USN, through COMNAVSURFOR, will have a difficult time justifying the adoption of RFID. In addition to the prospect of moving from a familiar technology to a new one and training USN personnel for competency, the cost of adopting RFID technology for materials will be up to 10 times more expensive than simply printing, affixing, and scanning barcodes created by IBS (Ozdemir & Bayrak, 2010).

Afloat SUPPOs reported spending up to 2 hours per day tracking the locations of spare parts and their on-hand quantities, and they were willing to commit OPTAR toward bringing RFID technologies onboard to automate these tasks if given the opportunity

(Doerr et al., 2006). In 2015, the USS *Independence* (LCS 2) completed a demonstration using passive RFID for inventory purposes: 1,300 pieces of equipment were successfully and accurately inventoried in 21 minutes. The USN reported that this same task would take 72 hours for three personnel to accomplish using IBS (Naval Surface Warfare Center, Panama City Division, 2015).

2. Blockchain Technology

A blockchain is defined as a chain of data structures, or blocks, that act as transactional ledgers containing information about individual items (Shaw, 2018; Siqueira & Correa, 2020). This information can include unit price updates, piece part inventories if the individual item is a kit or is complex in nature, locations that individual items have been to, point of contact information, and designated overhaul point locations. Figure 5 illustrates the blockchain concept.



A "hash" is a digital fingerprint that references a transaction and/or the block from which it originated. A chain is formed by having one block reference a previous block's hash, creating a verifiable trail of transactions and updates.

Figure 5. Blockchain Example. Source: Shyam (2018b).

One of the provisions for having a functional, accessible block is consensus: all unchanged pieces of information in the block must match previous versions unless a transaction that updates the information is certified by a network user, and no transactions can be erased or altered (Shyam, 2018b). By making these blocks a shared, distributed resource in a network of authorized users, the duplication of effort when inputting records and the additional man-hours needed to verify and validate the accuracy of records can be eliminated (Shyam, 2018a).

Blockchain applications follow the premise of decentralizing records associated with high money value or high-velocity items and making them transparent throughout an organization. Decentralization reduces the risk of inaccurate inventory information syncing to FIMARS if an afloat vessel experiences a communications interruption during deployment. The transparency and reliability of blockchain information is established "as long as every member of the [blockchain] network accesses the same data" through a common interface (Siqueira & Correa, 2020).

According to Siqueira and Correa (2020), the Naval Air Systems Command (NAVAIR) conducted a study to incorporate blockchain technology into aircraft maintenance processes. The SIMBA Chain platform enables NAVAIR to order from and make payments to spare parts suppliers automatically, to track shipments, and to fill out forms and other key supporting documents for inventory and procedural inspections. Because of blockchain's relative immaturity, its applications for improving inventory accuracy remain unexplored, with its key limitation being a lack of common infrastructure that is capable of translating blockchain information for legacy supply chain systems (Siqueira & Correa, 2020).

Additional limitations prevent the USN from adopting this technology. Conceptually, the blockchain concept contrasts with the paradigm of centralized information control within the DOD for security purposes (Ledger Insights, 2018). A review of blockchain platforms revealed that the information contained within blockchain records is not standardized (Shaw, 2018) and that the blockchain concept cannot fix records that were originally inaccurate or defective due to user error (Siqueira & Correa, 2020). The Government Accountability Office (GAO, 2019) reported that establishing a blockchain network will require significant, sustained computing power and energy, for which the USN may not have resources. They also identify the risk of collusion, where users within the network could influence each other to accept an intentional manipulation for auditability or proof-of-concept purposes (GAO, 2019).

D. THE NAVY'S INVENTORY ACCURACY WITH ITS CURRENT TECHNOLOGIES AND PROCESSES

FACET scanning helps substantiate newly received inventories of material for afloat vessels; however, due to limited connectivity while underway, FACET scans may not sync with shore-based servers until a vessel is in port and connected via pier services, which can take up to 3 weeks. In light of this, real-time inventory reporting is an issue when it comes to FACET. If a vessel is delayed in syncing their FACET scans, there is a possibility that items were issued or consumed before completing the sync.

IBS inventory accuracy is dependent on the competence of the personnel managing its inputs and outputs. If a person makes a mistake when inputting an NSN that needs to be inventoried to the scanner, then a discrepancy will output to the inventory report. According to the Lieutenant William Lynch, the principal assistant for logistics on the USS *America* (LHA 6), there is no standardized training for IBS; the training for operating and maintaining the system comes in the form of on-the-job training by the few people that are familiar with the system "with no clear guidance on how to use it" (W. Lynch, email to author, March 30, 2021).

The ATAC procedure, though proven and reliable, is dependent on a multitude of human labor to ensure procedural accuracy as a DLR moves through the DON's supply system. This creates an inherent risk of human error in the transfer of information whenever an item changes hands.

As a whole, COMNAVSURFPAC acknowledges that inventory discrepancies on afloat vessels originate from personnel noncompliance with procedures regarding proper material receipt and stowage (COMNAVSURFPAC, 2016). NAVAIR also admits that their desire to optimize the aviation supply chain stems from the significant impact that the human factor has on aviation safety mishaps (Siqueira & Correa, 2020).

E. STUDIES ON COST-BENEFIT ANALYSES OF TECHNOLOGY ADOPTION

This section reviews cost-benefit analyses on recently published academic works that cover similar topics associated with technology adoption and innovation.

1. Cost-Benefit Analysis of RFID Adoption

A 2012 report by James Gerber utilized a cost-benefit analysis to "analyze the adoption of [RFID] technology as one way in which [the Defense Microelectronics Activity] can achieve cost savings" (Gerber, 2011–2012). The immediate costs that were identified in Gerber's report were as follows:

- RFID labels
- RFID power supplies (if RFID labels are active and not passive)
- RFID readers and range boosters
- Software costs to utilize RFID capabilities

Categorization of more detailed costs resulted in three distinct areas: "capital expenditures, implementation costs, and training" (Gerber, 2011–2012).

The immediate benefits that were identified in Gerber's report included:

- Employee labor hour reduction
- Simple tracking of machine and component usage and the cost savings associated with using them for menial tasks instead of workers
- Failsafes in the event of process deviations and the cost savings from rework
- Cost savings from administrative work overlap associated with inventory items

After detailing additional benefits, three categories were identified for those benefits: "material tracking and control, shrinkage reduction, and cost of quality savings" (Gerber, 2011–2012).

Finally, non-monetary factors in Gerber's report centered mainly on the benefit of worker safety through the use of RFID automation. However, Gerber attempted "to capture the main dollar benefits in a systematic way, without quantifying non-dollar benefits" and leaving it up to decision makers and readers to "compare the net dollar benefits (or costs) predicted by the [analysis] against the non-dollar benefits separately" (Gerber, 2011–2012).

After reviewing the model presented by Gerber, the author intends to employ a similar cost-benefit analysis by identifying tangible, monetary costs and benefits for use within the analysis itself. Meanwhile, the author intends to discuss significant nonmonetary factors that could influence the decision to adopt new technologies for inventory accuracy, but the author does not intend to monetize these factors for use in the analysis.

2. Cost-Benefit Analysis of New Aircraft Adoption

The 2019 report by Scott Adams and David Tickle used a cost-benefit analysis to weigh alternatives for the "Navy Flight Demonstration Squadron's (Blue Angels) transition from the … F/A-18 Legacy Hornet" (Adams & Tickle, 2019). The impact categories within their analysis included aircraft procurement, aircraft modification, flight testing, and normal operations as their main costs; and foreign military sales, key influencer programs, and media flights as their main benefits (Adams & Tickle, 2019). Their analysis was conducted using two alternatives to the F/A-18 Legacy Hornet: adopt the F/A-18 Super Hornet or adopt the F-35C Lightning II. Additionally, a sensitivity analysis was conducted "to recognize uncertainty in the [cost-benefit analysis] model" and to account for that uncertainty through itemized variable adjustments (Adams & Tickle, 2019).

After reviewing the model presented by Adams and Tickle, and in addition to the methodology the author adopted from the 2012 RFID cost-benefit analysis, the author intends to identify two alternatives in their cost-benefit analysis and apply a sensitivity analysis for uncertain variables if necessary.

F. SUMMARY

This chapter reviewed the DON's inventory policies, their consideration and use of previously adopted commercial technologies, and the processes involved with the technologies in place that contribute to reliable inventory accuracy. This chapter also reviewed cost-benefit analysis models from past cases that substantiate the author's use of different variables in their own analysis.

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III. CURRENT COMMERCIAL TECHNOLOGIES

This chapter explores technologies used in the civilian sector that provide real-time inventory accuracy with very little to no discrepancies. Outlining these technologies and applying them to the needs of the DON should reveal a method that it can adopt to better keep track of high money value and high-velocity inventory.

A. ZAPPOS

Amazon purchased Zappos in 2009 for $928 million in a deal that allowed Zappos to maintain its independence while Amazon gained access to inventory control technologies (Lacy, 2009). Amazon's most notable asset acquired in the Zappos deal was its distribution centers. These 825,000 square foot facilities are four stories high with 128 carousels, 23,000 feet of conveyors continuously running throughout the day, and enough shelves to hold 3.7 million units of inventory (Burke & Ewing, 2014). Figure 6 shows an example of a Zappos fulfillment center.

Each product on Zappos's shelves has a barcode that annotates what item it is and on which shelf it is located.

Figure 6. A Zappos Fulfillment Center. Source: lizzielaroo (2006).

Zappos's procedures require workers to immediately tag newly received line items of inventory with an individualized barcode, unlike IBS's barcodes assigned based on NSN or NIIN. Receiving personnel in one of 20 receiving stations scan the item's manufacturer UPC with a handheld scanner. The scanner's software then identifies and assigns a location to store the item, and it prints the individualized barcode for the receiver to affix to the item. These individual barcodes allow items to be stored anywhere in a distribution center with a completely accurate location "instead of storing like items together in the same location" (Burke & Ewing, 2014).

When the time comes for an item to be pulled from inventory, Zappos's automated system identifies the item's location and directs a picker to it. The picker uses an RFID scanner to scan the item, which eliminates the need for picking tickets and other paperwork required to match item numbers, locations, and quantities in an order. Once scanned, the item is placed on a takeaway conveyor to be prepared for shipment, and once the item is shipped, its quantity and location is subtracted from the overall inventory. This system keeps real-time inventory of each item in its inventory between receipt and shipment departure (Burke & Ewing, 2014).

Zappos's procedures prove that automated storage is accurate in real time. When a distribution center was audited between 2012 and 2014, there was no record of an inventory discrepancy; automation mitigated the risk of human error despite its apparent lack of organization (Burke & Ewing, 2014). Zappos's "approach to inventory is directly related to its customer service philosophy: 'We don't want customers to be frustrated by ordering something and it's not there to ship'" (Zager, 2009).

B. XPO LOGISTICS

In 2017, XPO designed a testing ground to try different technologies intended for the establishment and maintenance of real-time inventory accuracy. Tested technologies include augmented reality and glasses that turn red if warehouse picking personnel choose the wrong item (Ashe, 2017). The most notable product adopted by XPO from the testing ground was XPO Connect. This application is a platform that provides a single-source solution for tracking materials in XPO's custody throughout the world and for tracing transactions. Companies that utilize XPO's platform and its embedded logistics services include IKEA, Zara, Banana Republic, and Old Navy (Smith, 2018).

In 2018, XPO deployed 5,000 autonomous robots that resemble large Roomba vacuum cleaners in its distribution centers throughout North America and Europe, and they are shown in Figure 7. These collaborative robots (or Cobots) use cameras, lasers, and RFID sensors to operate in groups and efficiently navigate warehouses. They use XPO Connect to determine the best warehouse location to fulfill an order and pick an item from inventory. Automating this process avoids "overlapping items and dropping those whose bar codes can't be read on the first round" (Smith, 2018). Some Cobots have grasping arms that reach high and/or heavy items; if this type of Cobot cannot obtain an item using its grasping arm, it will automatically call personnel in the distribution center that will remotely manipulate its grasping arm to pick the item (Smith, 2018).

Figure 7. Collaborative Robots (Cobots) Used by XPO Logistics.
Source: Smith (2018).

Mario Harik, the Chief Information Officer of XPO logistics in 2019, commented on XPO's adoption of Cobot technology:

> It used to be that in supply chain, you had to move pallets of goods and you had two weeks to get these pallets to the destination. … Supply chain leaders around the world are being pressured to deliver on that promise of speed down to the unit level and just-in-time inventory fulfillment, while keeping the costs equal, or even taking that cost down. (Shaw, 2018)

Mr. Harik was also on the record about Cobot productivity elsewhere:

> [Cobots have] significantly increased productivity with picking, packing and sorting tasks and reduced fulfillment time from multiple hours to 20 to 40 minutes. After redesigning the workflow in a way that made the best use of existing robotic technology, human productivity increased by four to five times and eliminated walking time by nearly 80%. (Lawton, 2019)

The premise behind Cobot technology is automating "menial, repetitive tasks" so that inventory personnel can "undertake more rewarding, mindful work" to achieve absolute, real-time inventory accuracy and process efficiency (Lawton, 2019).

There are two types of Cobots used by XPO Logistics. The first type works on aggregating orders while warehouse personnel walk alongside them, shown in Figure 8. These Cobots lead a warehouse picker to the shelf and/or bin where the item is located, and they show the warehouse picker a photo of the item to pick on its display. Once the item is taken and put inside the robot, the robot uses an RFID scanner to verify the item and autonomously moves toward a packing station to prepare the item for shipment (Shaw, 2019).

Figure 8. Collaborative Robots (Cobots) Working with Warehouse Personnel. Source: XPO Logistics (2019b).

The second type of Cobot ensures that warehouse picking personnel remain stationary at a packing station; these Cobots bring "mobile storage units, or MSUs" to warehouse pickers that contain the item needing to be picked. The MSUs are equipped with lights that illuminate the bins containing the required items, and a large display on the Cobot shows a photograph of the item that needs to be picked (Shaw, 2019). Figure 9 shows Cobots carrying MSUs.

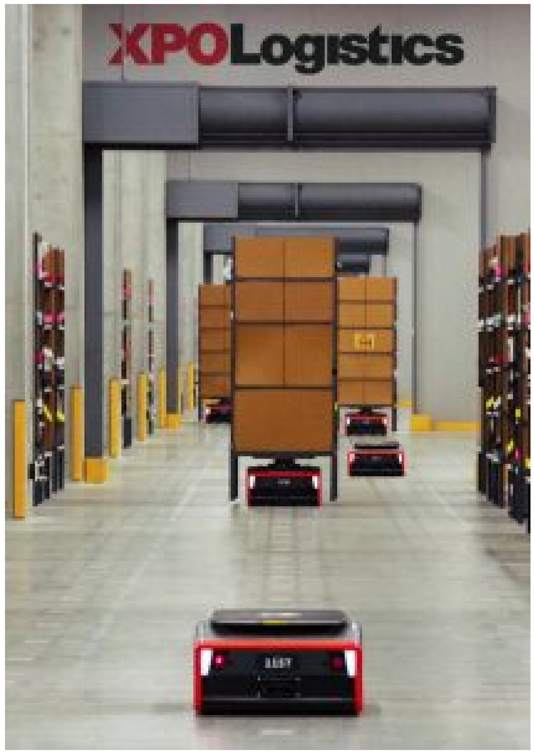

Figure 9. Collaborative Robots (Cobots) Carrying Batches of Items in MSUs. Source: XPO Logistics (2019a).

Cobots that have grasping arms for heavy and/or high lifting and that are equipped to carry MSUs are capable of carrying up to 3,500 pounds of material (Shu, 2018).

C. FLC JACKSONVILLE'S ROBOTIC PROCESSING AUTOMATION

This section covers FLC Jacksonville's innovation initiatives that significantly improved their inventory accuracy and worker productivity.

1. Warehouse Renovations

NAVSUP directed FLC Jacksonville to use the Material Exploratory Pilot Program (MEPP) to find a solution that maintains positive inventory control of all DLRs in its area of responsibility that requires repair. This positive inventory control meant real-time inventory accuracy from an inventory item's time of acceptance to its time of return to Navy Working Capital Fund inventory. NAVSUP's goal was to reduce transportation times by about 25% by eliminating redundant records and to save storage, processing, and material handling costs (M. Donnelly & S. Skirvin, PowerPoint slides, January 14, 2021). FLC Jacksonville spent $3.5 million to renovate an 80-year-old warehouse onboard Naval Air Station Jacksonville to prepare for the MEPP. The CO of NAVSUP FLC Jacksonville, Captain William H. Clarke, stated that the MEPP "aims to demonstrate how technology can improve audit readiness, lower management costs, and increase fleet lethality using RFID tagging and robotics" (Mcclanahan, 2020).

2. Autonomous Mobile Robot Technology

The MEPP introduced autonomous mobile robot (AMR) technology to use as part of FLC Jacksonville's new warehouse inventory process. AMR provides FLC Jacksonville with a tool set for collecting, monitoring, and reacting to key information about where a DLR is located in the warehouse. It uses lasers and cameras to navigate warehouses or storerooms, displaying a blue light in the path of where it intends to go. Additionally, it uses three active RFID readers located on the robot to obtain information from passive RFID tags affixed to items in their custody. This provides FLC Jacksonville with the ability to gather inventory data autonomously and constantly and to immediately warn users of any discrepancies. When this technology was showcased at the 2019 Sea Air Space Expo in National Harbor, MD, it was revealed that AMR "does not require an expensive fixed infrastructure to deploy and will enable NAVSUP to perform wall-to-wall inventories on a regular basis and exceed inventory validity goals" (Morrison, 2019). According to the sales manager of Fetch Robotics, Mr. Andre Chivalette, the AMR module weighs 200 pounds, has a height of 4 feet, 5 inches, and has a footprint diameter of 22.6 inches (A. Chivalette, email to author, April 16, 2021). Figure 10 shows an AMR module as showcased during the 2019 Sea Air Space Expo.

Figure 10. An AMR Module. Source: Morrison (2019).

The AMR technology used by FLC Jacksonville is owned by Fetch Robotics. It named its device "TagSurveyor" for its ability to read RFID tags up to 25 feet away and at a viewing angle of 82 degrees from the device's position (A. Chivalette, email to author, April 16, 2021). Figure 11 illustrates this concept.

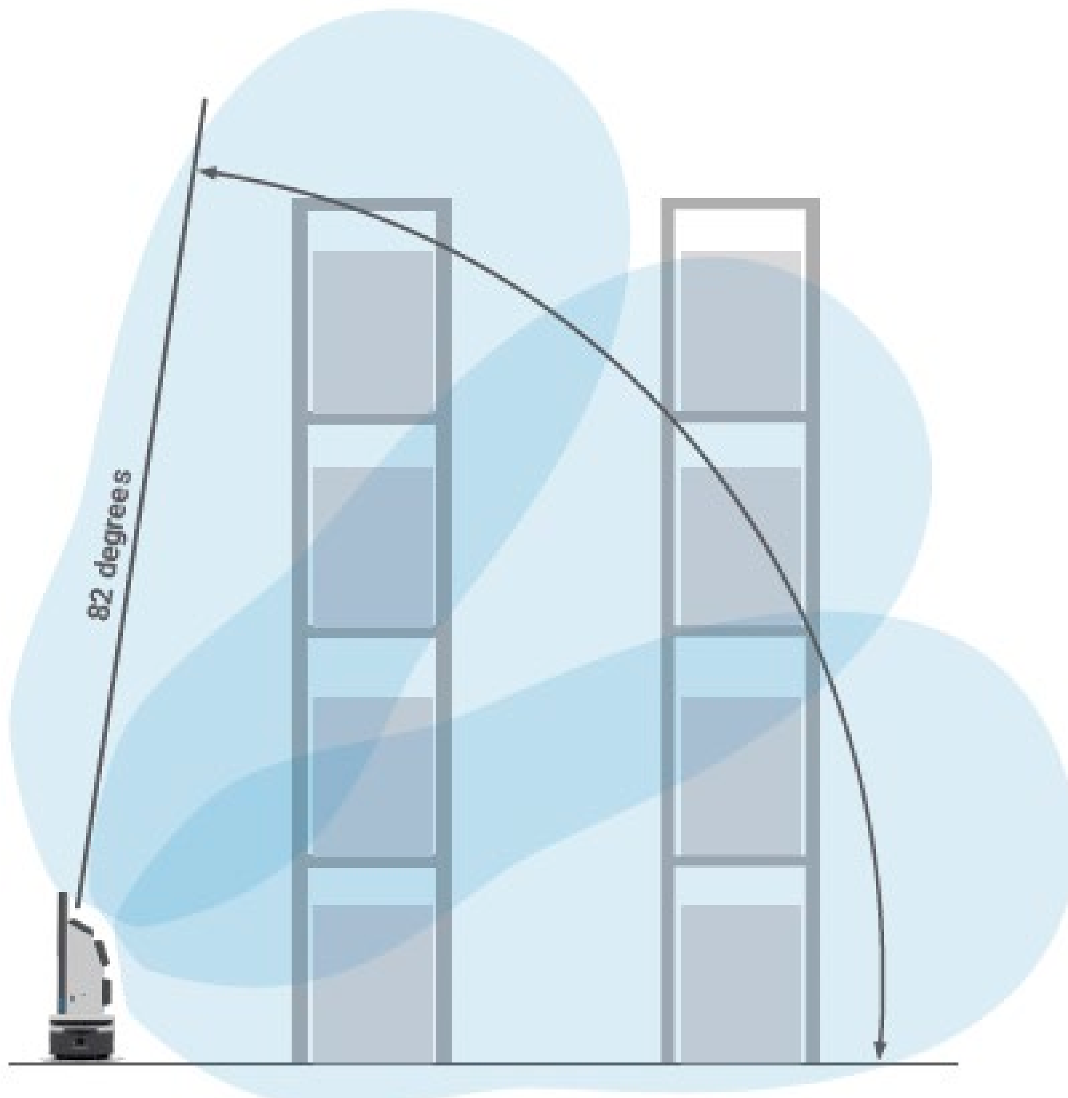

Figure 11. TagSurveyor AMR’s Reading Angle. Source: A. Chivalette (email to author, April 16, 2021).

Mr. Chivalette mentioned that there is no requirement for RFID tags to be within the AMR module’s line of sight, but it is highly recommended (personal communication, April 16, 2021). Additionally, if Wi-Fi or Hazard of Electromagnetic Radiation to Ordnance (HERO) requirements are an issue on afloat vessels or warehouses close to ordnance, the AMR modules can work through dead zones and continue their assigned workflow. The workflows that can be assigned to each TagSurveyor AMR is shown in Figure 12.

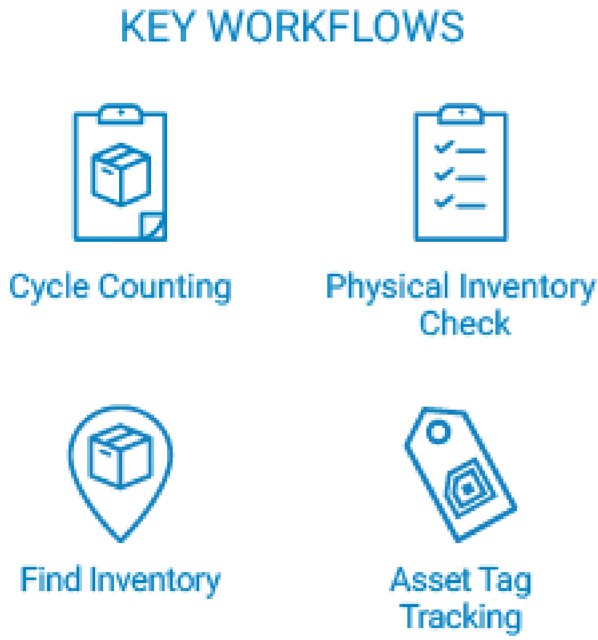

Figure 12. Assignable Workflows for TagSurveyor AMR Modules. Source: A. Chivalette (email to author, April 16, 2021).

D. RECOMMENDATION OF CURRENT TECHNOLOGY

In light of the information presented in both the previous chapter and this chapter, the author recommends the following technologies for the USN to adopt:

1. An application capable of interfacing with blockchain records and translating information to and from legacy USN inventory systems such as RSUPPLY, NALCOMIS, and ERP.
2. Warehouse and storeroom overhauls similar to that of NAVSUP FLC Jacksonville that can utilize robotic processing automation.
3. A Cobot system similar to the AMR technology showcased at the Sea Air Space Expo in 2019 that will enable partial or full automation of inventory picking procedures to reduce warehouse refusals or human error in fulfilling order requirements.

These technologies are all covered under Fetch Robotics. They have an information system called FetchCore that is capable of syncing information with ERP. In addition, they include warehouse mapping in their establishment services to mitigate a large overhaul of warehouses; the only requirement is for warehouse or storeroom personnel to affix passive

RFID tags on every piece of inventory. Finally, they are the proprietors of the AMR technology mentioned above.

E. SUMMARY

This chapter outlined technologies that the DON adopted for its inventory solutions and commercial technologies that are proven to contribute to real-time inventory accuracy.

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IV. COST-BENEFIT ANALYSIS OF RECOMMENDED COMMERCIAL TECHNOLOGY

This chapter presents an analysis of benefits and tradeoffs for the recommended technologies from the previous chapter. It includes a discussion of the monetary and nonmonetary costs and benefits of adopting the recommended technologies. The author follows the steps in Table 2, which are in accordance with the U.S. Office of Management and Budget (1992).

Table 2. The Major Steps in a Cost-Benefit Analysis. Source: Boardman et al. (2018).

1. Specify the set of alternative projects.
2. Decide whose benefits and costs have standing.
3. Identify impact categories, catalog them, and select measurement indicators.
4. Predict the impacts quantitatively over the life of the project.
5. Monetize all impacts.
6. Discount benefits and costs to obtain present values.
7. Compute the net present value of each alternative.
8. Perform sensitivity analysis.
9. Make a recommendation.

The alternatives are to (a) keep the USN's existing technologies for inventory accuracy or (b) adopt the systems recommended at the end of Chapter III. This cost-benefit analysis is conducted from a Navy-wide perspective, with NAVSUP having the principal role of acquiring these technologies. Therefore, the costs and benefits that will have standing involve those of the DON, NAVSUP, and its employees. Additionally, this cost-benefit analysis is conducted for shore-based facilities only; the implementation of GPS-enabled, cloud-based mapping of storerooms within the DON's afloat vessels is not feasible at this time.

A. MONETARY IMPACTS

This section outlines the factors that are already monetized or have a metric that can be monetized for use in the cost-benefit analysis. The assumptions used for evaluating these factors in U.S. dollars are as follows:

- All monetized impacts (positive or negative) are calculated in 2021 U.S. dollars.
- Material costs are incurred at the beginning of each specified time period.
- Labor costs are incurred at the end of each specified time period.
- Existing infrastructure is able to fully accommodate the adoption of technologies without the need for modification.
- The cost to train personnel and sustain proficiency with the new technology is included in each specified labor rate.

When analyzing monetized impacts (monetary costs and benefits), three distinct categories were identified: technology establishment following adoption, technology sustainment and the labor associated with it, and the costs and/or savings involving rework. These categories are discussed below.

1. Cost of Establishment

When Cobot technology was first introduced, there was little competition and a premium price for owning it. Such was the case when XPO Logistics designed and implemented its Cobot infrastructure: it had a budget of more than $550 million (Shaw, 2019). Luckily, as time passed and Cobot technology got "cheaper and easier to adopt," Cobots could be added "quickly to existing sites without disrupting operations" (Smith, 2018).

According to Andre Chivalette (personal communication, April 16, 2021), there are two ways to procure TagSurveyor AMRs. The first way is to lease the AMR for $2,500 per month, per module, with a lease term of 36 months. The second way is to buy the AMR module outright for $50,000 per module.

Regardless of how the AMR is procured, there is a one-time fee of $10,000 for mapping shore-based warehouses, building workflows according to NAVSUP's needs, and syncing information with ERP. It is unknown whether storeroom mapping on an afloat vessel is possible at this time due to mapping information being linked to GPS and the requirement to sync to Fetch Robotics's cloud. No major overhauls are necessary to map warehouses, but storeroom and warehouse personnel are required to affix printer-friendly passive RFID tags to each item in inventory. These RFID tags cost 10 cents each (A. Chivalette, personal communication, April 16, 2021).

FLC Jacksonville's preliminary business case estimates that initial investment costs, which include its warehouse renovation and establishment of AMR capabilities, will total $4,570,000 with a return on investment being possible after 20 months (M. Donnelly & S. Skirvin, PowerPoint slides, January 14, 2021).

2. Cost of Labor and Sustainment

With NAVSUP working to implement RFID technology, there is potential to reduce planned full-time employee requirements mentioned above. FLC Jacksonville's preliminary business case estimates that its total sustained costs for automated storage will be $911,338 per year (M. Donnelly & S. Skirvin, PowerPoint slides, January 14, 2021).

FLC Jacksonville's initial workforce for setting up its renovated warehouse involved the following:

- one site director
- one deputy site director
- one supervisory supply management specialist
- one material handler
- two contract warehouse specialists

Sustaining the warehouse means replacing the initial workforce with the following:

- one supervisory supply management specialist (one grade below the supervisory supply management specialist in the initial workforce)
- one supervisory inventory management specialist
- one inventory supply tech

In terms of sustainment, if NAVSUP chooses to lease AMR modules for 36-month increments, there is no cost for software and hardware support, including syncing with ERP, nor will there be costs for updates. If NAVSUP chooses to buy AMR modules outright, there is an annual fee of $10,000 for each AMR module after the first year of ownership (A. Chivalette, personal communication, April 16, 2021).

TagSurveyor AMRs have the capability of running for 9 hours on a single charge, and they take 3 hours to recharge to 90% capacity (A. Chivalette, personal communication, April 16, 2021). This would allow AMRs to work nonstop for 1 more hour compared to a typical worker's shift, which is 8 hours with a 1-hour break. XPO Chief Executive Brad Jacobs stated that Cobots such as TagSurveyor's AMR give users and customers "some protection against fluctuation in labor costs" (Smith, 2018).

3. Cost of Rework

The cost of rework is subjective; however, the author assumes the worst-case scenario for human error when inputting inventory records into the DON's systems today. If a single inventory record is found to have transposed numbers or other input errors on a high-velocity, high money value item, causative research may take up to 3 days of dedicated man-hours for two personnel to find the error. In addition, it will take up to 2 days of dedicated man-hours for one person to walk back transactions, administratively reverse the error, and rerun those transactions with the correct inventory amounts.

Additionally, adjusting inventory due to errors also incurs inventory adjustment costs on the administrative side that are identical to the inventoried item's unit price. When using FLC Jacksonville as a representative of the average inventory in NAVSUP's warehouses across the continental United States, there is a total of 6,200 pieces of material across 340 NIINs with a total cost of approximately $280 million (Mcclanahan, 2020; N. Powers, email to author, February 25, 2021).

B. NONMONETARY IMPACTS

This section discusses non-monetized, non-tangible factors that can significantly influence the decision of DON authorities to adopt Cobot technology. These factors revolve around the human element of adopting and/or sustaining a new technology: time, safety, and organizational acceptance. Because the value of time, safety, and organizational acceptance vary with each individual worker, these factors are an exceptional challenge to adequately monetize without bias. Although these factors are not be included as part of the computed analysis, they are important to keep in mind for the overall benefit of organizational environments that are considering adoption of Cobot technology.

1. Time

Typically, personnel are entitled to periodic breaks while on their shift. Automated processes and Cobot technology eliminate the need for these periodic breaks, therefore increasing the number of productive hours in the day.

Following establishment, Cobot technology reduces the training time for inventory processes considerably. New employees will need to familiarize themselves with only one information system with fewer input prompts.

Adopting automated technology provides DON personnel an additional benefit: the USN would no longer have a requirement to manually verify the accuracy of inventory-related processes, which would save man-hours for more productive and meaningful work.

2. Safety

According to TechTarget.com writer George Lawton, "One of the biggest challenges with robots working around people is completely ensuring a [Cobot] will not harm a human worker" (Lawton, 2019). If Cobot technology is implemented with a sound strategy that addresses worker safety, personnel in warehouses will no longer have to walk for miles daily, nor will they have to bend or lift heavy items and risk injury. Vehicular accidents involving pallet jacks, warehouse carts, and forklifts will also be greatly reduced if heavy-lifting Cobots with mechanical arms are adopted.

3. Organizational Acceptance

A combination of time and safety benefits stemming from automated inventory processes can influence an organization's acceptance of the new technology. However, automated technologies may jeopardize the job security of warehouse workers, particularly those that work in facilities holding large amounts of DON material that need periodic inventory. If warehouse workers in a fleet concentration area wish to prioritize their job security, it could negatively impact the implementation and sustainment of Cobot technology in those areas.

C. ANALYSIS OF ALTERNATIVES

The labor calculations for establishing and sustaining new technologies are assuming that a typical workday includes 8 paid hours and that all civilian positions are new hires under Step 1 of the 2021 general schedule's basic hourly rate, shown in Appendix A. Military labor calculations are based on the 2021 military pay chart, shown in Appendix B. Additionally, despite the varying sizes of each shore-based FLC, it is assumed that manpower requirements will remain the same for each location due to the nature of work associated with adopting this technology.

1. Keeping Current Technologies

If NAVSUP chooses to keep current technologies, the following will apply:

a. Establishment costs

The systems in place with NAVSUP's shore-based facilities today require no establishment or installation cost.

b. Labor and Sustained Costs

For medium sized activities that are required to keep NWCF inventory, the average labor rates are as follows:

- One site director (O-4 with an average of 12 years in service): $8,066.70 per month
- One deputy site director (O-3 with an average of 6 years in service): $6,311.70 per month
- One supervisory supply management specialist (GS-12): $32.02 per hour × 8 hours per workday × 20 workdays per month = $5,123.20 per month

- Two supply inventory techs (GS-7): \$18.05 per hour × 8 hours per workday × 20 workdays per month × 2 people = \$5,776 per month

- Two logistics specialists (E-5s with an average of 8 years in service): \$3,405.60 × 2 people = \$6,811.20 per month

- One material handler (GS-6): \$16.24 per hour × 8 hours per workday × 20 workdays per month = \$2,598.40 per month

c. Rework Costs

Assuming that warehouses encounter the worst-case scenario discussed in the previous section once every 2 months:

- Finding the error with two logistics specialists: \$3,405.60 / 30 days × 3 days × 2 people = \$681.12 of additional work / 2 months = \$340.56 of additional work per month

- Correcting the error with one logistics specialist: \$3,405.60 / 30 days × 2 days × 1 person = \$227.04 of additional work / 2 months = \$113.52 of additional work per month

- Administrative inventory adjustments: \$280,000,000 / 6,200 line items / 2 months = \$22,580.65 of administrative inventory adjustments per month

d. Total Costs

- Zero one-time establishment costs

- \$8,066.70 + \$6,311.70 + \$5,123.20 + \$5,776 + \$6,811.20 + \$2,598.40 + \$340.56 + \$113.52 + \$22,580.65 = \$57,721.93 per month for labor and rework

The total monthly costs for keeping current technologies will serve as the baseline for determining whether it is worthwhile to lease or own TagSurveyor AMRs over time.

2. Leasing TagSurveyor AMR for 36 Months

If NAVSUP chooses to lease the TagSurveyor AMR for 36 months, the following will apply:

a. Establishment Costs

- \$10,000 warehouse mapping, workflow building, and record syncing fee + (\$0.10 RFID tags × 6,200 line items) = \$10,620 to map the warehouse and establish RFID capability
- Add temporary billet for one site director (O-4 with an average of 12 years in service): \$8,066.70 per month for 3 months
- Add temporary billet for one deputy site director (O-3 with an average of 6 years in service): \$6,311.70 per month for 3 months
- Temporarily hire or assign one supervisory supply management specialist (GS-12): \$32.02 per hour × 8 hours per workday × 20 workdays per month = \$5,123.20 per month for 3 months
- Temporarily hire or assign one material handler (GS-6): \$16.24 per hour × 8 hours per workday × 20 workdays per month = \$2,598.40 per month for 3 months
- Contract two warehouse specialists: \$15 per hour × 8 hours per workday × 20 workdays per month = \$2,400 per month for 3 months

b. Labor and Sustainment Costs

- \$2,500 lease per month × 36 months = \$90,000 leasing cost every 36 months
- Hire one supervisory supply management specialist (GS-11): \$26.72 per hour × 8 hours per workday × 20 workdays per month = \$4,275.20 per month

- Hire one supervisory inventory management specialist (GS-8): \$19.99 per hour × 8 hours per workday × 20 workdays per month = \$3,198.40 per month

- Hire one inventory supply tech (GS-7): \$18.05 per hour × 8 hours per workday × 20 workdays per month = \$2,888 per month

- TagSurveyor AMR charging costs, given a run time of 9 hours (A. Chivalette, email to author, April 16, 2021): (3 hours / 90%) × 2 charges per day × 1.8 kW[1] × \$0.1031 per kilowatt-hour[2] = \$1.2372 per day × 30 days = \$37.116 or \$37.12 per month

c. Rework Costs

Because the inventory process will be automated, there will be no rework costs to consider following proper establishment of automated services.

d. Total Costs

- \$10,620 one-time cost

- \$90,000 leasing cost every 36 months = \$2,500 per month

- \$8,066.70 + \$6,311.70 + \$5,123.20 + \$2,598.40 + \$2,400 = \$24,500 per month for 3 months

- \$4,275.20 + \$3,198.40 + \$2,888 + \$37.12 = \$10,398.72 per month for labor, sustainment, and rework following establishment

3. Acquiring TagSurveyor AMR

Finally, if NAVSUP chooses to acquire the TagSurveyor AMR and its associated systems outright, the following will apply:

[1] kW are *kilowatts*, calculated by multiplying the standard voltage (120V) and amperes (15A) in the United States and dividing the product by 1,000.

[2] This is the average commercial rate for electricity usage in the United States (U.S. Energy Information Administration, n.d.).

a. Establishment Costs

- $50,000 purchase of TagSurveyor AMR
- $10,000 warehouse mapping, workflow building, and record syncing fee + ($0.10 RFID tags × 6,200 line items) = $10,620 to map the warehouse and establish RFID capability
- Add temporary billet for one site director (O-4 with an average of 12 years in service): $8,066.70 per month for 3 months
- Add temporary billet for one deputy site director (O-3 with an average of 6 years in service): $6,311.70 per month for 3 months
- Temporarily hire or assign one supervisory supply management specialist (GS-12): $32.02 per hour × 8 hours per workday × 20 workdays per month = $5,123.20 per month for 3 months
- Temporarily hire or assign one material handler (GS-6): $16.24 per hour × 8 hours per workday × 20 workdays per month = $2,598.40 per month for 3 months
- Contract two warehouse specialists: $15 per hour × 8 hours per workday × 20 workdays per month = $2,400 per month for 3 months

b. Labor and Sustainment Costs

- $10,000 per year after the first year of ownership
- Hire one supervisory supply management specialist (GS-11): $26.72 per hour × 8 hours per workday × 20 workdays per month = $4,275.20 per month
- Hire one supervisory inventory management specialist (GS-8): $19.99 per hour × 8 hours per workday × 20 workdays per month = $3,198.40 per month

- Hire one inventory supply tech (GS-7): $18.05 per hour × 8 hours per workday × 20 workdays per month = $2,888 per month
- TagSurveyor AMR charging costs, given a run time of 9 hours (A. Chivalette, email to author, April 16, 2021): (3 hours / 90%) × 2 charges per day × 1.8 kW × $0.1031 per kilowatt-hour = $1.2372 per day × 30 days = $37.116 or $37.12 per month

c. Rework Costs

Because the inventory process will be automated, there will be no rework costs to consider following proper establishment of automated services.

d. Total Costs

- $60,620 one-time cost
- $10,000 per year after the 1st year = $833.34 per month after the 1st year
- $8,066.70 + $6,311.70 + $5,123.20 + $2,598.40 + $2,400 = $24,500 per month for 3 months
- $4,275.20 + $3,198.40 + $2,888 + $37.12 = $10,398.72 per month for labor, sustainment, and rework following establishment

4. Comparing Total Costs over Time

Figure 13 is a graphical depiction of the total costs that accumulate over the first 6 months for each of the three alternatives. Figure 14 extends that depiction between 6 and 18 months. Figure 15 further extends the depiction between 18 and 36 months.

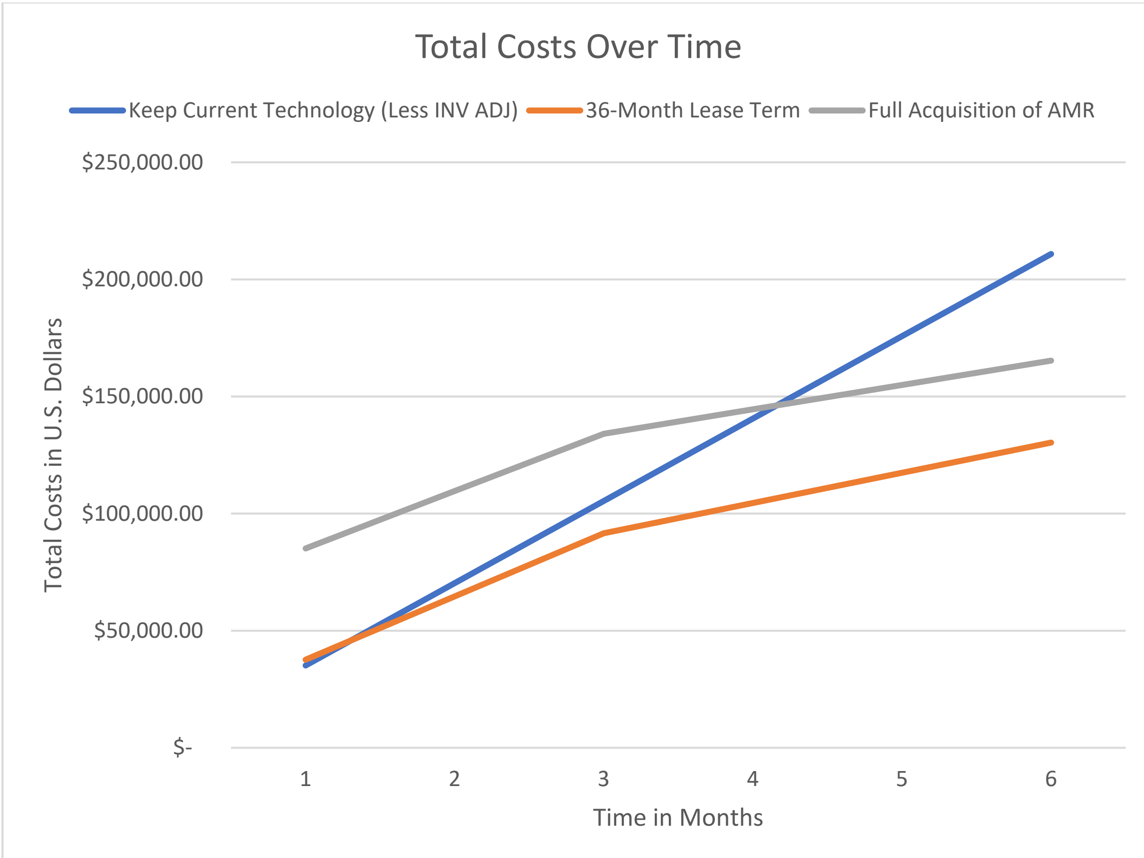

Figure 13. Total Costs over 6 Months for Technology Alternatives

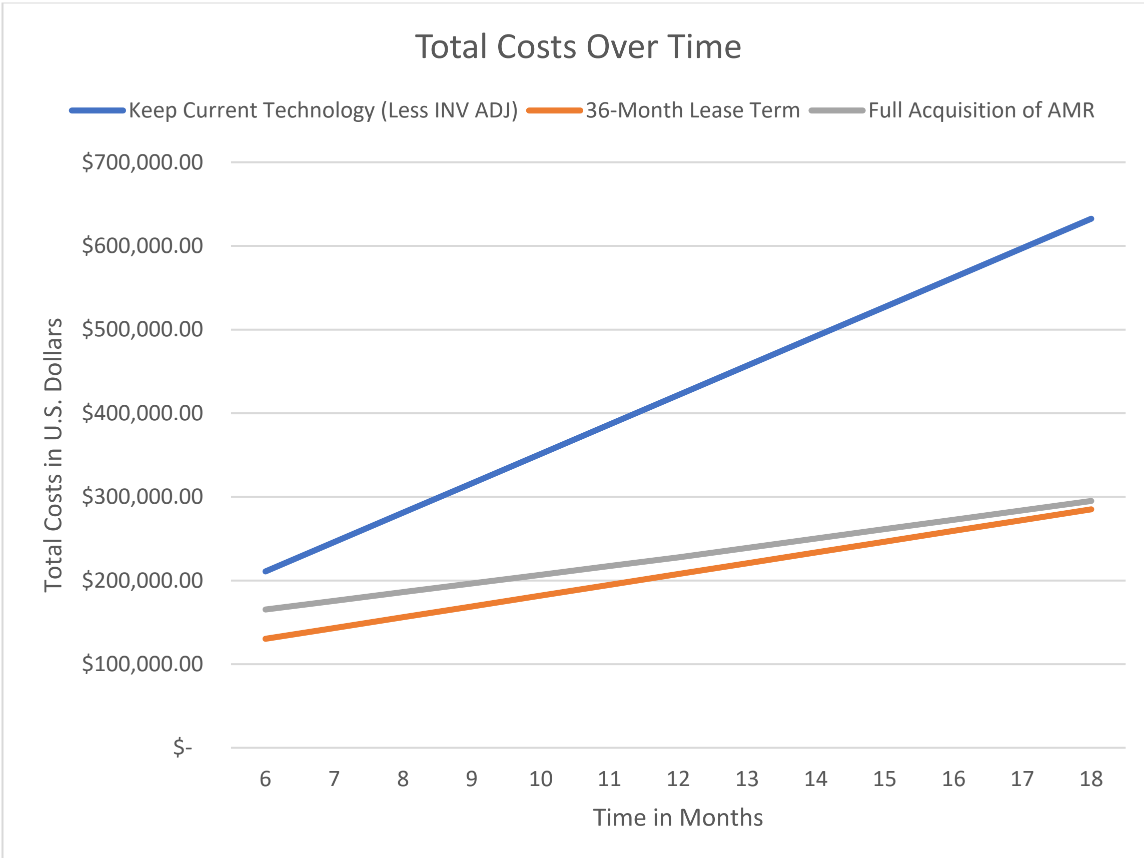

Figure 14. Total Costs between 6 and 18 Months for Technology Alternatives

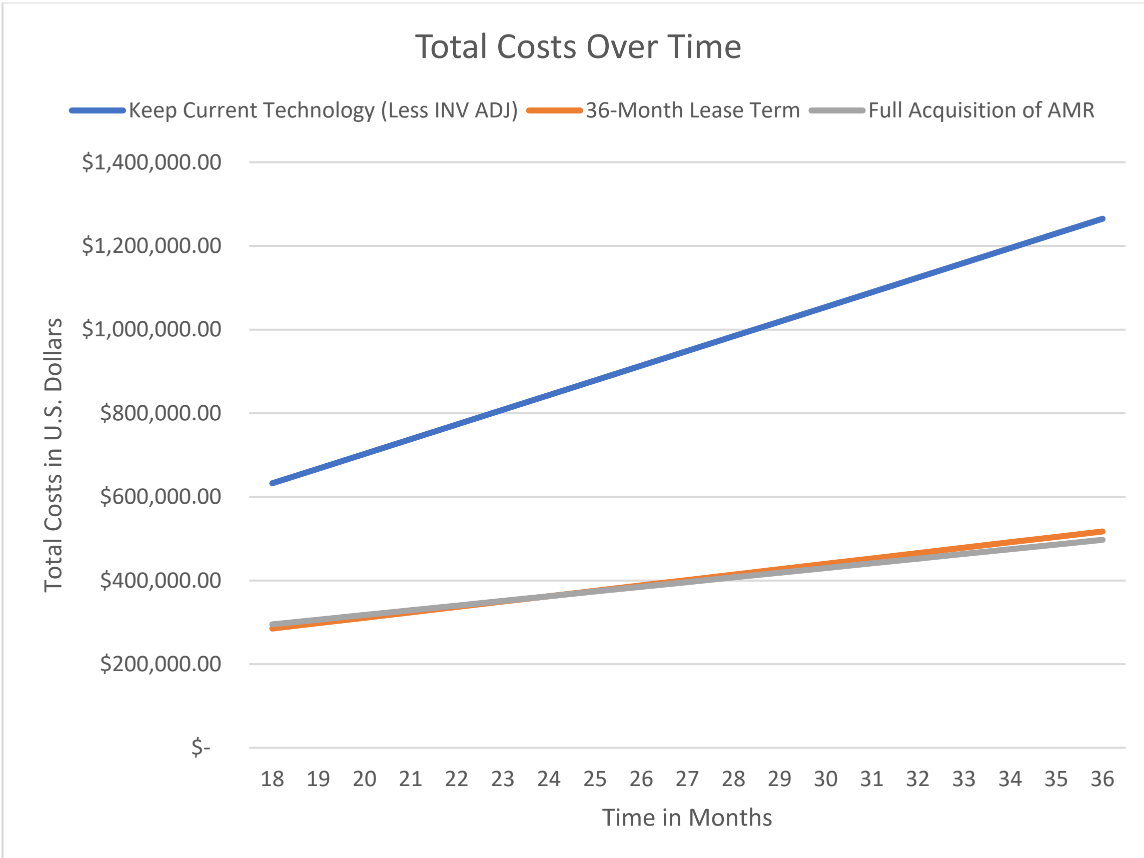

Figure 15. Total Costs between 18 and 36 Months for Technology Alternatives

If NAVSUP keeps its currently adopted technologies and processes, it is prone to the worst-case scenario of making an inventory discrepancy due to common human errors such as miscounting, transposing input numbers during the inventory process, or a combination of both. Although the probability of making an error gets lower with warehouse personnel training and individual due diligence, because of the length and verification requirements that the DON has in its processes, mistakes due to human error can be expected at any point in the inventory process. Therefore, the author projects rework costs to contribute to personnel payroll in a linear fashion as time progresses.

Second, if NAVSUP chooses to lease a TagSurveyor AMR module for 36 months, establishment costs will be $2,478.72 higher than keeping the DON's current technology for only the 1st month; NAVSUP will break even with the sustained costs of keeping current technologies shortly after the AMR's establishment, and it will see a total cost improvement of $5,662.56 after the 2nd month compared to keeping current technologies. Over the 36-month term of the lease, the total costs will remain significantly lower than those of current technologies.

Lastly, should NAVSUP acquire a TagSurveyor AMR module outright, establishment costs will be $49,978.72 higher than keeping current technologies. These costs remain higher over the establishment period of 3 months, but the difference between the two costs gets progressively lower over time. After the 4th month, the total cost of acquiring the AMR and its systems is $3,953.60 higher; after the 5th month, it is $20,788.96 lower, and it remains significantly lower than keeping current technologies from that point forward. On the 24th month, the total costs of leasing an AMR versus buying one breaks even, with the total costs of buying an AMR being the lowest out of the three alternatives afterward.

D. SENSITIVITY ANALYSIS OF ALTERNATIVES

Sensitivity analyses are conducted in order to recognize and account for uncertainties in through itemized variable adjustments (Adams & Tickle, 2019).

The most significant issue in this analysis is the assumption that every shore based FLC has approximately the same quantities and dollar values in their inventories. The distribution of DON assets throughout the continental United States directly influences the levels of inventory that each FLC holds, and sites that are located in fleet concentration areas such as Norfolk, VA or San Diego, CA will certainly hold more inventory line items that have a higher dollar value. Because of the limited data provided to the author, it is likely that the actual costs of establishment, sustainment, and rework will be significantly higher for those sites. Conversely, it is also likely that the costs and benefits discussed in this analysis will be significantly lower at FLC sites that do not have as many DON assets in the area when compared to FLC Jacksonville.

Additionally, although the author assumes that the existing warehouse infrastructure at each FLC site is sufficient enough to fully accommodate the adoption of technologies without the need for modification, each FLC CO may exercise the option to fully renovate warehouses that will accommodate newly adopted Cobot technology in a similar manner as FLC Jacksonville. If this were the case, renovation costs and the labor rates associated with them vary widely between each FLC site; they are all located in different states, and these states have individual policies regarding labor rates, taxes, and pricing of materials and services. Regardless of the location, exercising the option to renovate warehouses in anticipation of Cobot technology adoption will significantly increase establishment costs for both the 36-month lease alternative and the full acquisition alternative. If establishment costs increase for both of these alternatives, then the amount of time needed to break even with the costs of keeping current technologies in place will increase.

E. SUMMARY

This chapter detailed both monetary and nonmonetary costs associated with the technologies recommended in Chapter III. These costs were calculated, compiled, and translated into graphical form to visually represent cumulative costs of each alternative over time. One alternative shows the most potential beneficial for the DON after 25 months: acquiring a TagSurveyor AMR module outright. A sensitivity analysis was also conducted to address uncertainties and potential variations in the decision to adopt this new technology.

V. CONCLUSION AND RECOMMENDATIONS

NAVSUP has an enduring concern that the DON does not have sufficient record keeping, processes, or controls in place for the management of its physical assets, and this generates a negative impact on the U.S. Navy's readiness in multiple theaters. In an effort to improve readiness, this study attempted to identify and evaluate processes and technologies that the DON can adopt from private industry best-practices to improve both their inventory accuracy and their responsiveness to supply-related requirements.

Using a review of prior studies and analyzing data on inventory metrics and performance from successful commercial entities, this research study attempted to address the following research question:

> What processes, and technologies can the DON adopt from private industry best-practices to increase their inventory accuracy and improve their responsiveness to supply-related requirements?

The analysis of monetary and nonmonetary costs and cost-savings opportunities associated with the inventory technologies identified for potential adoption recommended, the overall findings show that the alternative with the most potential beneficial for the DON after 25 months is acquiring a TagSurveyor AMR module outright.

This final chapter makes a bottom-line recommendation based on researched information, literary reviews, and a cost-benefit analysis of alternatives presented in the previous chapters. The chapter also identifies limitations in the author's analysis, as well as areas that can be expounded upon through further research.

1. Final Recommendations

In light of all of the information presented in the previous chapters, the author recommends fully acquiring one TagSurveyor AMR for each FLC site in the contiguous United States and Hawaii. Although the cumulative costs will start much higher than if the DON keeps its current technologies, the overall monetary and nonmonetary benefits will be significant after 2 years. Warehouse personnel will be empowered to perform less menial, repetitive work; they will be in a safer working environment; and inventory metrics and milestones dictated by NAVSUP and U.S. Navy Type Commanders will be met or exceeded more consistently while saving man-hours and taxpayer dollars from being wasted on rework.

2. Challenges, Limitations of Findings, and Areas of Further Research

The greatest challenge to fully acquiring and implementing TagSurveyor AMRs at each FLC site is the acceptance of significant changes by each FLC site's organizational culture. Although the quality of life for warehouse personnel may improve, the automation of processes that have been performed by warehouse personnel for years may jeopardize their job security, especially for those that work in facilities holding large amounts of DON material that need periodic inventory. If warehouse workers in a fleet concentration area wish to prioritize their job security, it could negatively impact the implementation and sustainment of TagSurveyor AMRs in those areas by delaying or denying the adoption of automated technology outright.

Limitations were identified by the proprietor of the recommended technology, including the inability to accurately map afloat storerooms using GPS-enabled, cloud-based services. The author recommends conducting further research into whether the mapping of afloat storerooms can be conducted without GPS or cloud-based services and whether storeroom maps can be saved on a local server onboard.

Additionally, costs for FLC Jacksonville were used to represent the average inventory cost across all shore-based warehouses in the continental United States. This is certainly not the case in fleet-concentrated areas such as San Diego or Norfolk, where a large depth of DLR and high-velocity inventory is necessary to service all customers in their regions. The author recommends obtaining specific DLR and high-velocity inventory data and costs, along with payroll data for managing DLR and high-velocity inventory from each FLC to provide more specific results tailored to each site.

Finally, no data were researched for FLC sites in foreign countries, such as the logistics nodes in Yokosuka, Japan; Manama, Bahrain; and Sigonella, Italy. The author recommends obtaining data associated with establishing and sustaining AMR technologies, which should include the cost of travel for new hires, the average commercial electricity rates in each country, and other sustainment costs such as government housing.

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APPENDIX A. 2021 GENERAL SCHEDULE, HOURLY RATE PAY TABLE

Hourly Basic (B) Rates by Grade and Step
Hourly Title 5 Overtime (O) Rates for FLSA-Exempt Employees by Grade and Step

Grade	B/O	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
1	B	$ 9.46	$ 9.77	$ 10.09	$ 10.40	$ 10.72	$ 10.90	$ 11.21	$ 11.52	$ 11.54	$ 11.83
	O	*14.19*	*14.66*	*15.14*	*15.60*	*16.08*	*16.35*	*16.82*	*17.28*	*17.31*	*17.75*
2	B	10.63	10.89	11.24	11.54	11.67	12.01	12.35	12.70	13.04	13.38
	O	*15.95*	*16.34*	*16.86*	*17.31*	*17.51*	*18.02*	*18.53*	*19.05*	*19.56*	*20.07*
3	B	11.60	11.99	12.38	12.76	13.15	13.54	13.92	14.31	14.70	15.08
	O	*17.40*	*17.99*	*18.57*	*19.14*	*19.73*	*20.31*	*20.88*	*21.47*	*22.05*	*22.62*
4	B	13.03	13.46	13.89	14.33	14.76	15.20	15.63	16.06	16.50	16.93
	O	*19.55*	*20.19*	*20.84*	*21.50*	*22.14*	*22.80*	*23.45*	*24.09*	*24.75*	*25.40*
5	B	14.57	15.06	15.54	16.03	16.52	17.00	17.49	17.97	18.46	18.95
	O	*21.86*	*22.59*	*23.31*	*24.05*	*24.78*	*25.50*	*26.24*	*26.96*	*27.69*	*28.43*
6	B	16.24	16.79	17.33	17.87	18.41	18.95	19.49	20.03	20.58	21.12
	O	*24.36*	*25.19*	*26.00*	*26.81*	*27.62*	*28.43*	*29.24*	*30.05*	*30.87*	*31.68*
7	B	18.05	18.65	19.26	19.86	20.46	21.06	21.66	22.26	22.87	23.47
	O	*27.08*	*27.98*	*28.89*	*29.79*	*30.69*	*31.59*	*32.49*	*33.39*	*34.31*	*35.21*
8	B	19.99	20.66	21.32	21.99	22.66	23.32	23.99	24.66	25.32	25.99
	O	*29.99*	*30.99*	*31.98*	*32.99*	*33.99*	*34.98*	*35.99*	*36.48*	*36.48*	*36.48*
9	B	22.08	22.82	23.55	24.29	25.02	25.76	26.50	27.23	27.97	28.70
	O	*33.12*	*34.23*	*35.33*	*36.44*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*
10	B	24.32	25.13	25.94	26.75	27.56	28.37	29.18	29.99	30.80	31.61
	O	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*
11	B	26.72	27.61	28.50	29.39	30.28	31.17	32.06	32.95	33.84	34.73
	O	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*
12	B	32.02	33.09	34.16	35.22	36.29	37.36	38.43	39.49	40.56	41.63
	O	*36.48*	*36.48*	*36.48*	*36.48*	*36.48*	*37.36*	*38.43*	*39.49*	*40.56*	*41.63*
13	B	38.08	39.35	40.62	41.89	43.15	44.42	45.69	46.96	48.23	49.50
	O	*38.08*	*39.35*	*40.62*	*41.89*	*43.15*	*44.42*	*45.69*	*46.96*	*48.23*	*49.50*
14	B	45.00	46.50	48.00	49.50	51.00	52.49	53.99	55.49	56.99	58.49
	O	*45.00*	*46.50*	*48.00*	*49.50*	*51.00*	*52.49*	*53.99*	*55.49*	*56.99*	*58.49*
15	B	52.93	54.69	56.46	58.22	59.98	61.75	63.51	65.28	67.04	68.81
	O	*52.93*	*54.69*	*56.46*	*58.22*	*59.98*	*61.75*	*63.51*	*65.28*	*67.04*	*68.81*

Source: U.S. Office of Personnel Management (2021).

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APPENDIX B. 2021 MILITARY BASIC PAY TABLE

FY20 NDAA 3.0% increase

MONTHLY BASIC PAY TABLE

EFFECTIVE 1 JANUARY 2021

YEARS OF SERVICE

PAY GRADE	<2	2	3	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
COMMISSIONED OFFICERS																						
O-10*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30
O-9*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16012.50	16243.80	16576.80	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30	16608.30
O-8	11329.50	11701.20	11947.50	12016.20	12323.40	12836.70	12956.40	13443.60	13584.00	14004.00	14611.80	15171.90	15546.00	15546.00	15546.00	15546.00	15935.40	15935.40	16333.20	16333.20	16333.20	16333.20
O-7	9414.30	9851.40	10053.90	10215.00	10506.00	10794.00	11126.70	11458.20	11791.20	12836.70	13719.30	13719.30	13719.30	13719.30	13789.80	13789.80	14065.80	14065.80	14065.80	14065.80	14065.80	14065.80
O-6**	7139.10	7842.90	8357.70	8357.70	8389.80	8749.20	8796.90	8796.90	9296.70	10180.50	10699.20	11217.60	11512.80	11811.90	12390.90	12390.90	12638.40	12638.40	12638.40	12638.40	12638.40	12638.40
O-5	5951.40	6704.40	7168.20	7255.50	7545.60	7718.40	8099.40	8379.60	8740.80	9293.10	9555.90	9816.00	10111.20	10111.20	10111.20	10111.20	10111.20	10111.20	10111.20	10111.20	10111.20	10111.20
O-4	5135.10	5943.90	6341.10	6429.00	6797.10	7192.20	7684.20	8066.70	8332.50	8485.50	8573.70	8573.70	8573.70	8573.70	8573.70	8573.70	8573.70	8573.70	8573.70	8573.70	8573.70	8573.70
O-3***	4514.70	5117.70	5523.30	6022.80	6311.70	6628.20	6832.80	7169.40	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20	7345.20
O-2***	3901.20	4442.70	5116.80	5289.90	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50	5398.50
O-1***	3385.80	3524.40	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60	4260.60
COMMISSIONED OFFICERS WITH OVER 4 YEARS ACTIVE DUTY SERVICE AS AN ENLISTED MEMBER OR WARRANT OFFICER****																						
O-3E	0.00	0.00	0.00	6022.80	6311.70	6628.20	6832.80	7169.40	7453.50	7617.00	7839.00	7839.00	7839.00	7839.00	7839.00	7839.00	7839.00	7839.00	7839.00	7839.00	7839.00	7839.00
O-2E	0.00	0.00	0.00	5289.90	5398.50	5570.40	5860.50	6084.90	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70	6251.70
O-1E	0.00	0.00	0.00	4260.60	4549.50	4717.50	4889.70	5058.30	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90	5289.90
WARRANT OFFICERS																						
W-5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8296.20	8716.80	9030.60	9377.10	9377.10	9846.90	9846.90	10338.60	10338.60	10856.40	10856.40
W-4	4665.90	5018.70	5162.70	5304.60	5548.80	5790.30	6035.10	6402.60	6725.10	7032.00	7283.40	7528.50	7888.20	8183.70	8520.90	8520.90	8691.00	8691.00	8691.00	8691.00	8691.00	8691.00
W-3	4261.20	4438.50	4620.90	4680.30	4870.80	5246.40	5637.30	5821.50	6034.80	6253.80	6648.90	6915.00	7074.30	7243.50	7474.50	7474.50	7474.50	7474.50	7474.50	7474.50	7474.50	7474.50
W-2	3770.40	4127.10	4236.60	4312.20	4556.40	4936.50	5125.20	5310.30	5537.10	5714.40	5874.60	6066.90	6193.20	6293.10	6293.10	6293.10	6293.10	6293.10	6293.10	6293.10	6293.10	6293.10
W-1	3309.30	3666.00	3761.40	3963.90	4203.00	4555.80	4720.20	4950.90	5177.40	5355.60	5519.40	5718.60	5718.60	5718.60	5718.60	5718.60	5718.60	5718.60	5718.60	5718.60	5718.60	5718.60
ENLISTED MEMBERS																						
E-9	0.00	0.00	0.00	0.00	0.00	0.00	5637.00	5764.80	5925.90	6114.90	6306.60	6612.00	6871.50	7143.30	7560.30	7560.30	7937.70	7937.70	8334.90	8334.90	8752.50	8752.50
E-8	0.00	0.00	0.00	0.00	0.00	4614.60	4818.60	4944.90	5096.10	5260.50	5556.30	5706.30	5961.60	6103.50	6451.80	6451.80	6581.40	6581.40	6581.40	6581.40	6581.40	6581.40
E-7	3207.60	3501.00	3635.40	3812.40	3951.30	4189.50	4323.90	4561.80	4760.10	4895.10	5039.10	5094.90	5282.40	5382.90	5765.40	5765.40	5765.40	5765.40	5765.40	5765.40	5765.40	5765.40
E-6	2774.40	3053.10	3188.10	3318.90	3455.40	3762.60	3882.90	4114.50	4185.30	4236.90	4297.20	4297.20	4297.20	4297.20	4297.20	4297.20	4297.20	4297.20	4297.20	4297.20	4297.20	4297.20
E-5	2541.60	2712.90	2844.00	2978.10	3187.20	3405.60	3585.30	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90	3606.90
E-4	2330.40	2449.80	2582.40	2713.50	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00	2829.00
E-3	2103.90	2236.20	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80	2371.80
E-2	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70	2000.70
E-1 >4 Mon	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00	1785.00
E-1 <4 Mon	1650.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

* Basic pay is limited to the rate of basic pay for level II of the Executive Schedule in effect during calendar year 2021, which is $16,608.30 per month for officers at pay grades O-7 through O-10. This includes officers serving as Chairman or Vice Chairman of the Joint Chiefs of Staff, Chief of Staff of the Army, Chief of Naval Operations, Chief of Staff of the Air Force, Commandant of the Marine Corps, Chief of Space Operations, Commandant of the Coast Guard, Chief of the National Guard Bureau, or commander of a unified or specified combatant command (as defined in 10 U.S.C. 161(c)).

** Basic pay is limited to the rate of basic pay for level V of the Executive Schedule in effect during calendar year 2021, which is $13,475.10 per month, for officers at pay grades O-6 and below.

*** Does not apply to commissioned officers who have been credited with over 4 years of active duty service as an enlisted member or warrant officer.

**** Reservists with at least 1,460 points as an enlisted member, a warrant officer, or a warrant officer and an enlisted member which are creditable toward reserve retirement also qualify for these rates.

Source: Defense Finance and Accounting Service (2021).

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APPENDIX C. COST-BENEFIT ANALYSIS DATA POINTS

	Keep Current Technology	Keep Current Technology (Less Inventory Adjustments)	36-Month Lease Term	Full Acquisition of AMR
Months	Cost	Cost	Cost	Cost
1	$ 57,721.93	$ 35,141.28	$ 37,620.00	$ 85,120.00
2	$ 115,443.86	$ 70,282.56	$ 64,620.00	$ 109,620.00
3	$ 173,165.79	$ 105,423.84	$ 91,620.00	$ 134,120.00
4	$ 230,887.72	$ 140,565.12	$ 104,518.72	$ 144,518.72
5	$ 288,609.65	$ 175,706.40	$ 117,417.44	$ 154,917.44
6	$ 346,331.58	$ 210,847.68	$ 130,316.16	$ 165,316.16
7	$ 404,053.51	$ 245,988.96	$ 143,214.88	$ 175,714.88
8	$ 461,775.44	$ 281,130.24	$ 156,113.60	$ 186,113.60
9	$ 519,497.37	$ 316,271.52	$ 169,012.32	$ 196,512.32
10	$ 577,219.30	$ 351,412.80	$ 181,911.04	$ 206,911.04
11	$ 634,941.23	$ 386,554.08	$ 194,809.76	$ 217,309.76
12	$ 692,663.16	$ 421,695.36	$ 207,708.48	$ 227,708.48
13	$ 750,385.09	$ 456,836.64	$ 220,607.20	$ 238,940.54
14	$ 808,107.02	$ 491,977.92	$ 233,505.92	$ 250,172.60
15	$ 865,828.95	$ 527,119.20	$ 246,404.64	$ 261,404.66
16	$ 923,550.88	$ 562,260.48	$ 259,303.36	$ 272,636.72
17	$ 981,272.81	$ 597,401.76	$ 272,202.08	$ 283,868.78
18	$ 1,038,994.74	$ 632,543.04	$ 285,100.80	$ 295,100.84
19	$ 1,096,716.67	$ 667,684.32	$ 297,999.52	$ 306,332.90
20	$ 1,154,438.60	$ 702,825.60	$ 310,898.24	$ 317,564.96

	Keep Current Technology	Keep Current Technology (Less Inventory Adjustments)	36-Month Lease Term	Full Acquisition of AMR
21	$ 1,212,160.53	$ 737,966.88	$ 323,796.96	$ 328,797.02
22	$ 1,269,882.46	$ 773,108.16	$ 336,695.68	$ 340,029.08
23	$ 1,327,604.39	$ 808,249.44	$ 349,594.40	$ 351,261.14
24	$ 1,385,326.32	$ 843,390.72	$ 362,493.12	$ 362,493.20
25	$ 1,443,048.25	$ 878,532.00	$ 375,391.84	$ 373,725.26
26	$ 1,500,770.18	$ 913,673.28	$ 388,290.56	$ 384,957.32
27	$ 1,558,492.11	$ 948,814.56	$ 401,189.28	$ 396,189.38
28	$ 1,616,214.04	$ 983,955.84	$ 414,088.00	$ 407,421.44
29	$ 1,673,935.97	$ 1,019,097.12	$ 426,986.72	$ 418,653.50
30	$ 1,731,657.90	$ 1,054,238.40	$ 439,885.44	$ 429,885.56
31	$ 1,789,379.83	$ 1,089,379.68	$ 452,784.16	$ 441,117.62
32	$ 1,847,101.76	$ 1,124,520.96	$ 465,682.88	$ 452,349.68
33	$ 1,904,823.69	$ 1,159,662.24	$ 478,581.60	$ 463,581.74
34	$ 1,962,545.62	$ 1,194,803.52	$ 491,480.32	$ 474,813.80
35	$ 2,020,267.55	$ 1,229,944.80	$ 504,379.04	$ 486,045.86
36	$ 2,077,989.48	$ 1,265,086.08	$ 517,277.76	$ 497,277.92
		% Cost Reduction	75%	76%

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